TWO STAGE STOCHASTIC MODELS FOR CONTRACTING DECISIONS OF AN INDUSTRIAL CONSUMER

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CONTENT

- Motivation and objective
- Deterministic approach
- Probabilistic approach
- Numerical application
- Conclusions
- Future developments

MOTIVATION and OBJECTIVE

❑ Motivation:

- ✓ Industrial consumers may negotiate with retailers price and format of the contracts they sign for supplying their energy needs
- ✓ Need for new mathematical tools for industrial consumers in liberalized markets

❑ Objective:

- ✓ Development of a decision support model for contracting and operation decisions in the medium term with the following features:
  - Integrated tool: contract and operation optimization and price generation modules
  - Single to parameterize models
  - Data easily available

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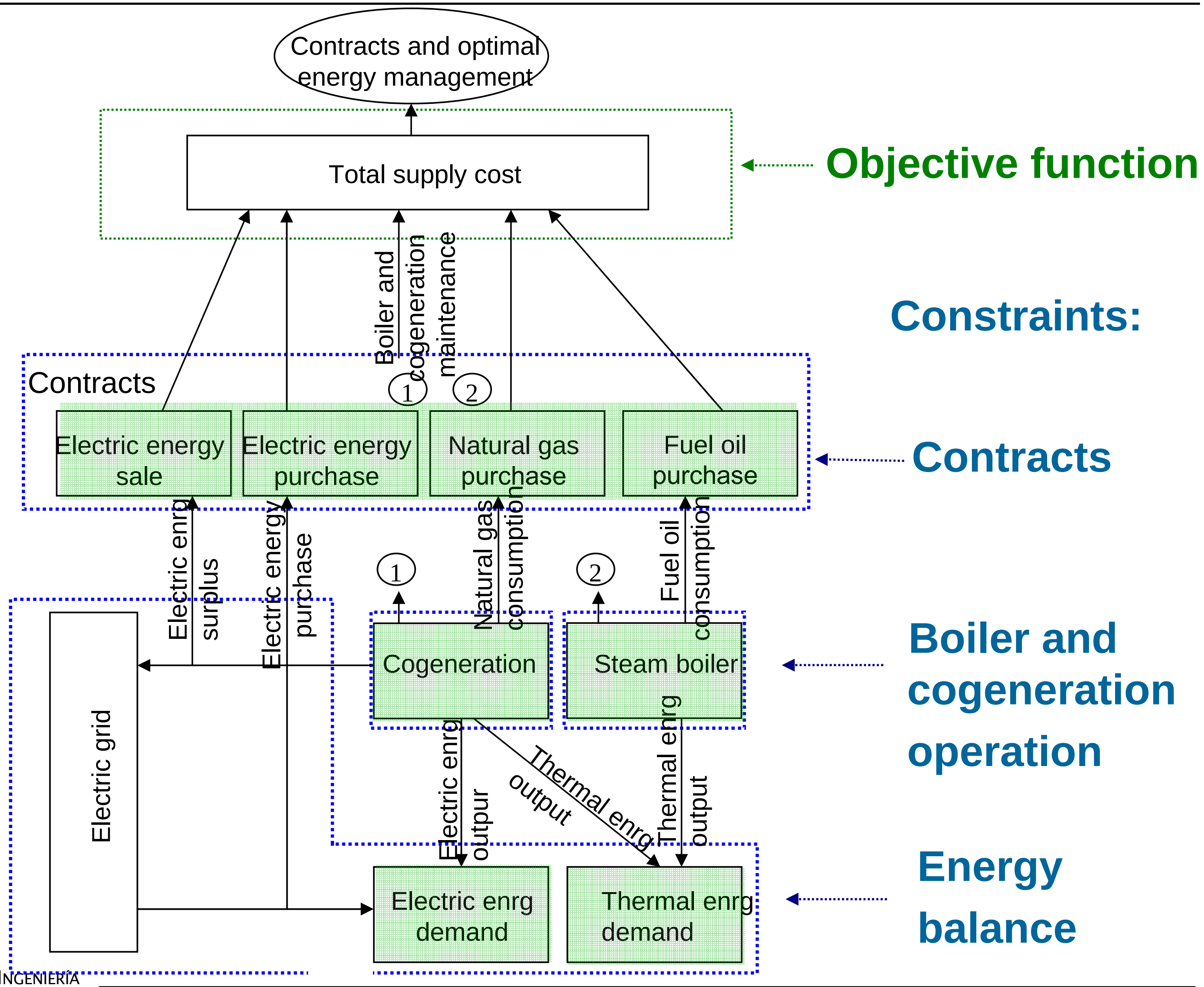
DETERMINISTIC APPROACH
General features

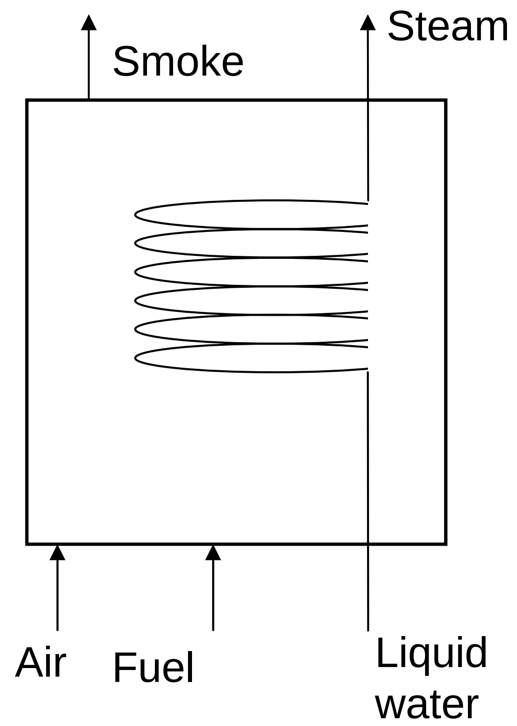
- **Medium term energy management**
  - ✓ Minimization of the supply cost
- **Yearly scope**
- **Industrial consumer with thermal and electric demand**
  - ✓ Cogeneration
  - ✓ Steam boiler
- **Decisions**
  - ✓ Contracts for energy supply
  - ✓ Boiler and cogeneration operation

DETERMINISTIC APPROACH
General features



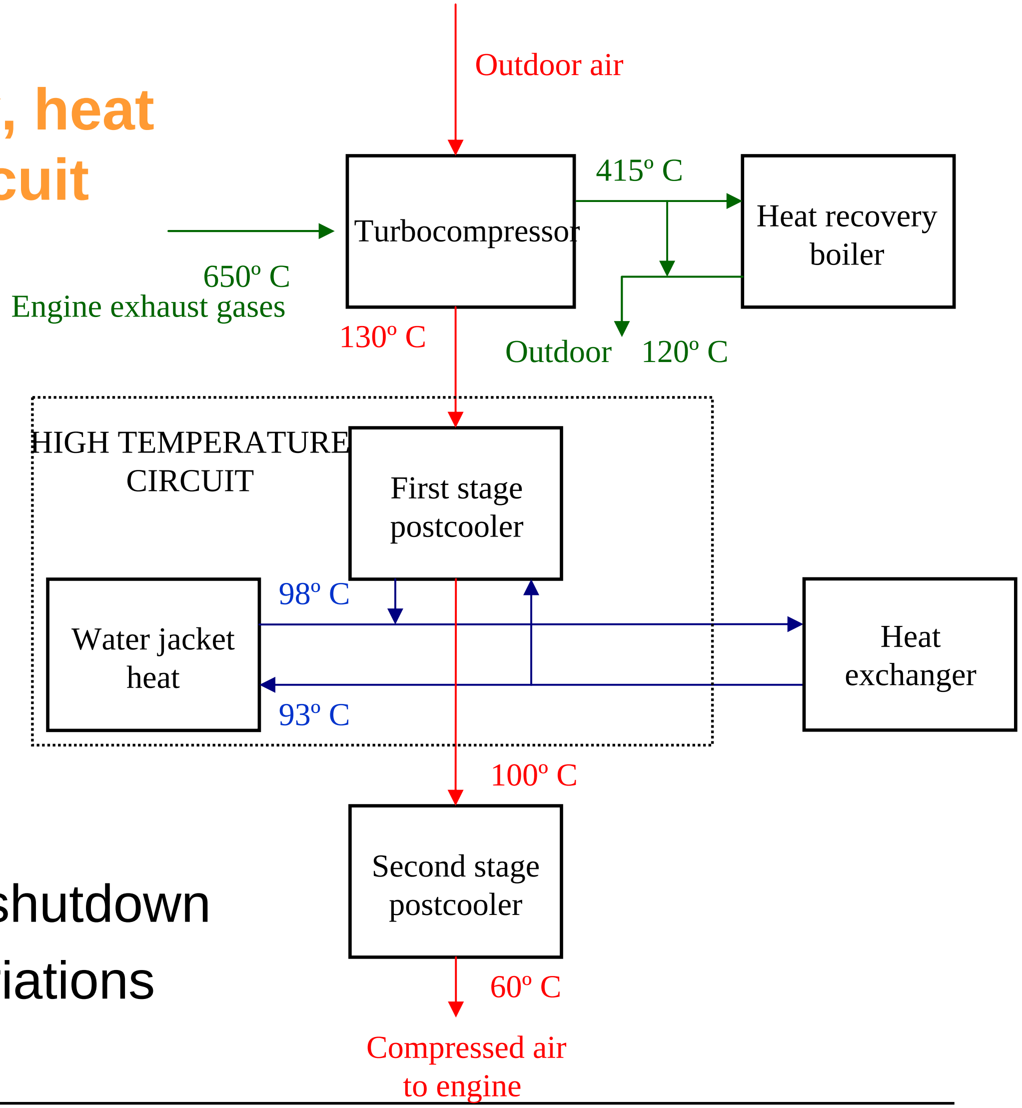
DETERMINISTIC APPROACH
Steam boiler

- ❑ **Boiler fed by fuel oil**
- ❑ **Linear relation between fuel oil consumption and steam produced**
- ❑ **Operation limits**
- ❑ **Costs:**
  - ✓ Fuel oil consumption
  - ✓ Operation cost per kg of fuel oil consumed
  - ✓ Yearly maintenance
- ❑ **Simplifications:**
  - ✓ Cost and time for startup and shutdown
  - ✓ Input and output enthalpies



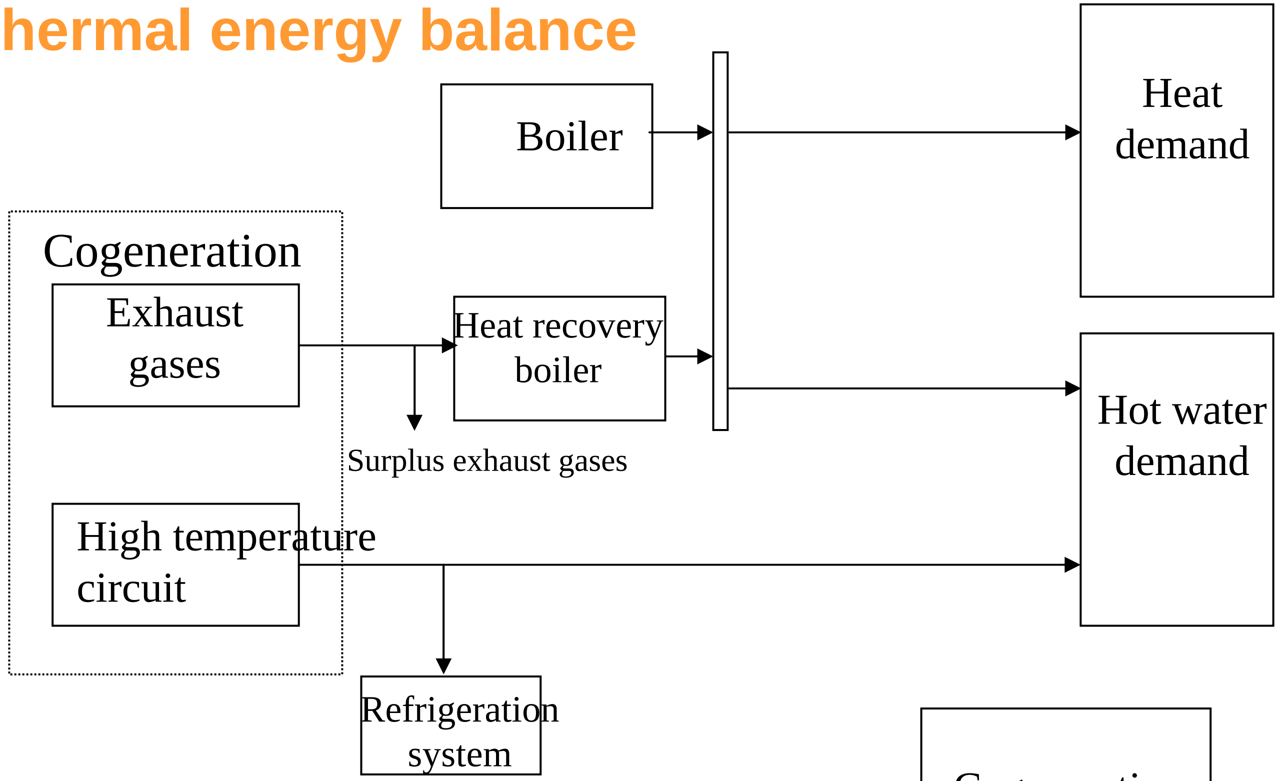
DETERMINISTIC APPROACH
Cogeneration

- Engine fed by natural gas
- Linear relation between gas consumption and: electricity, heat from exhaust gases, H.T. circuit
- Operation limits
- Special regime
- Costs:
  - ✓ Natural gas consumption
  - ✓ Operation cost per kWh of electricity generated
  - ✓ Yearly maintenance
- Simplifications:
  - ✓ Cost and time for startup and shutdown
  - ✓ Temperature and pressure variations

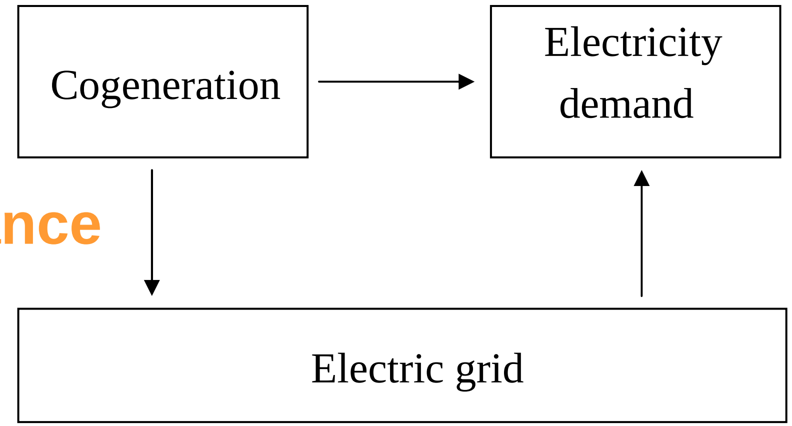


DETERMINISTIC APPROACH
Energy balance

Thermal energy balance

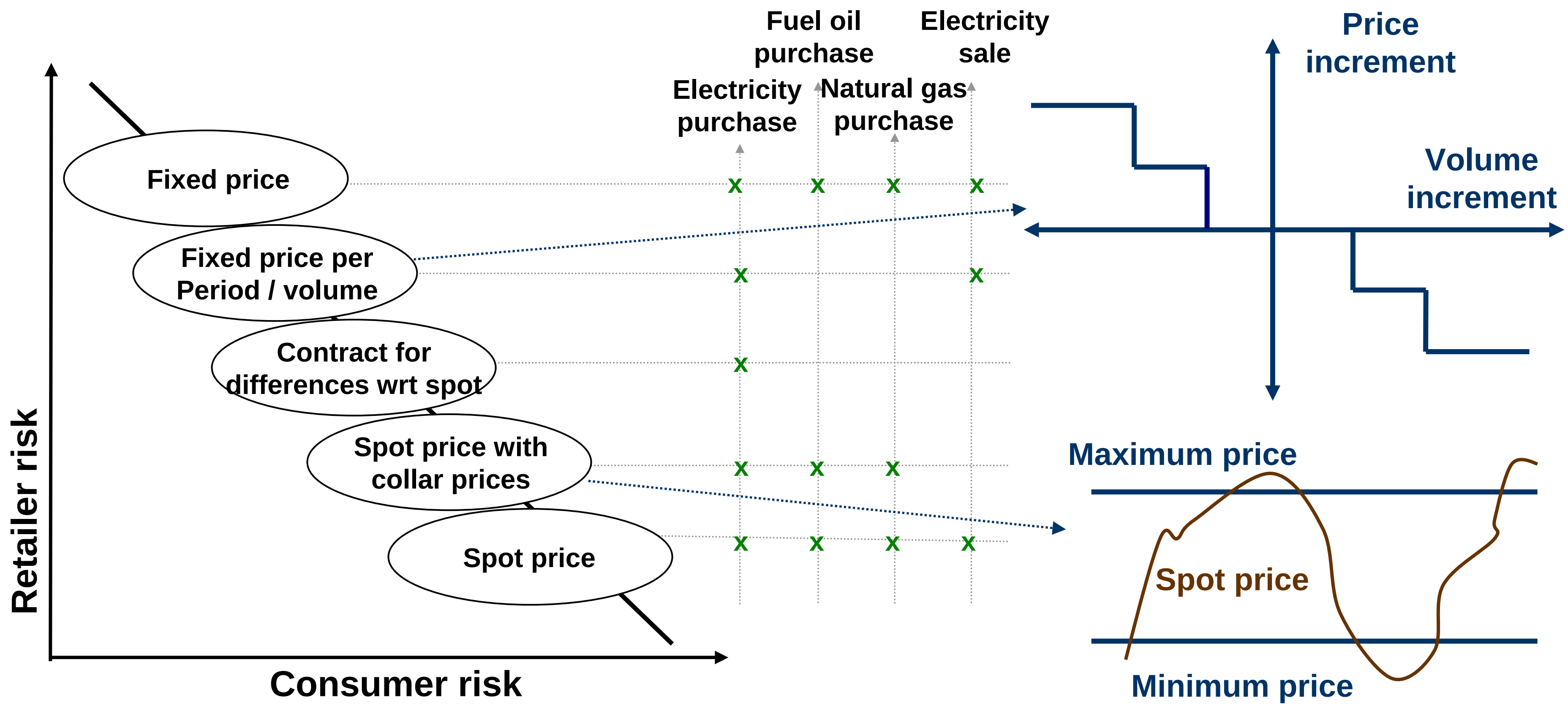


Electric energy balance



DETERMINISTIC APPROACH
Contracts

- Main decisions of the model
- Only one yearly contract is chosen per type
- Contract with different risk aversion are modeled



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STOCHASTIC APPROACH
General features

- **Deterministic approach**
  - ✓ Limited in uncertainty modeling
- **Stochastic optimization**
  - ✓ Allows to take decisions explicitly considering the parameter uncertainty
- **Risk sources for industrial consumers**
  - ✓ **Price risk**
  - ✓ Quantity risk: system failure or demand fluctuations
  - ✓ Other risks: credit and regulatory

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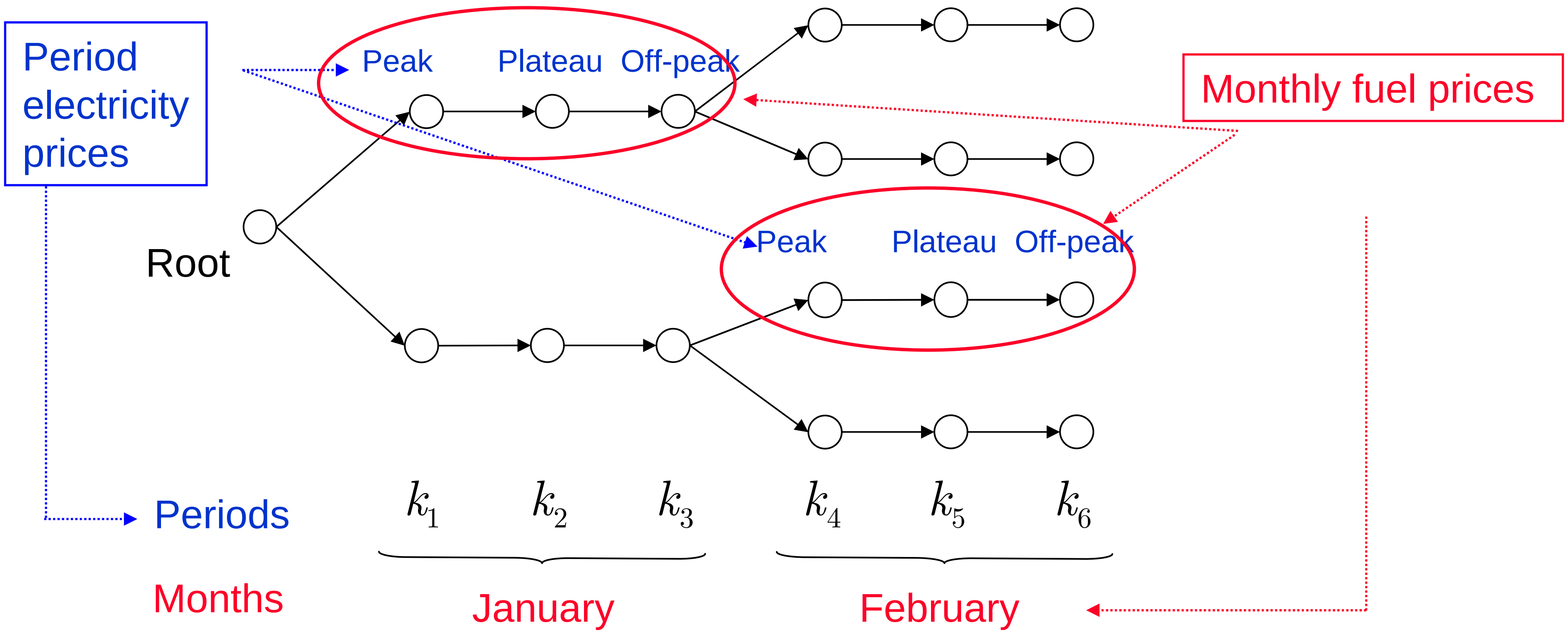
Stochastic parameter: sale and purchase prices of electricity, natural gas and fuel oil

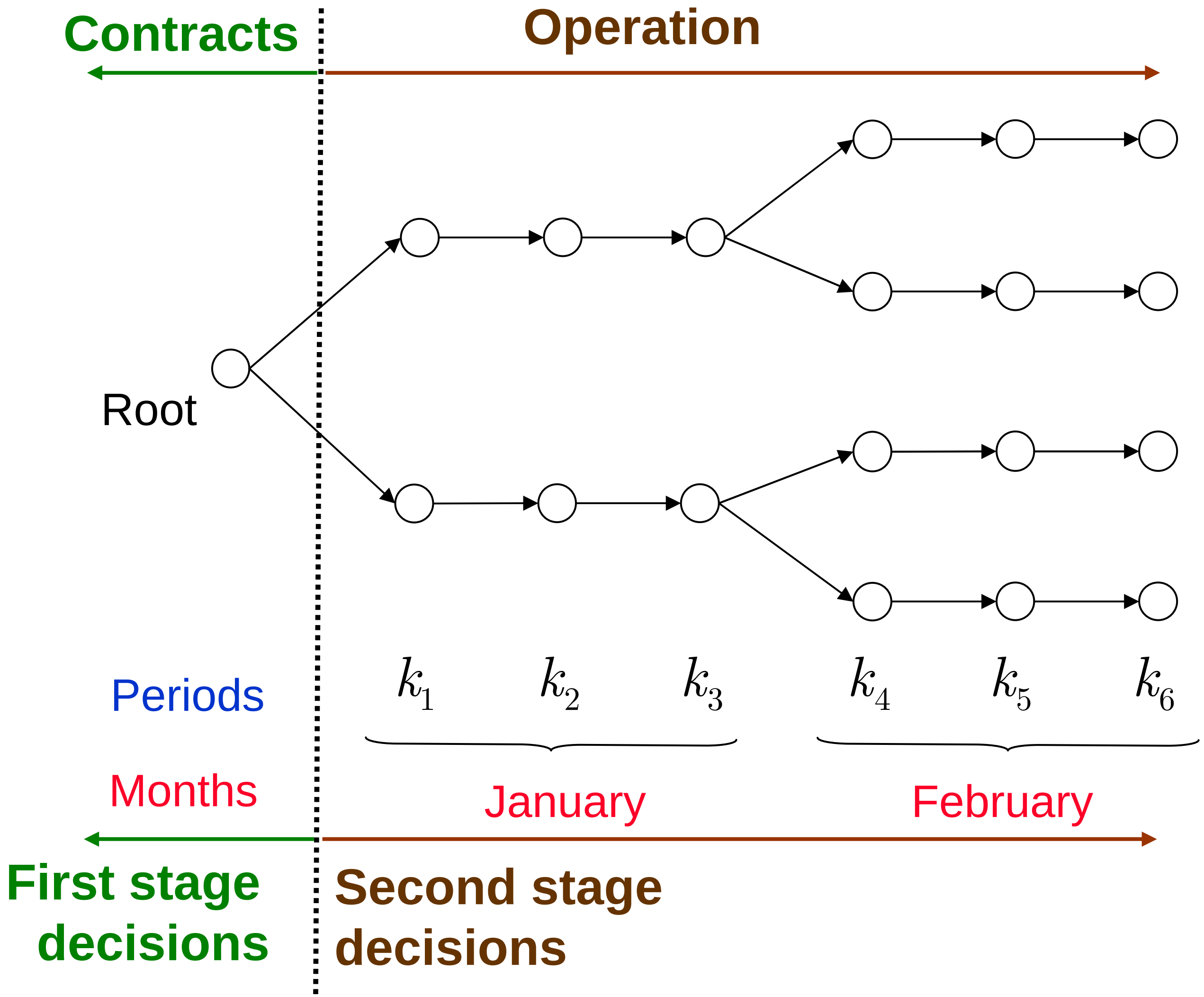
STOCHASTIC APPROACH
Uncertainty modeling

- ❑ **Discrete representation of the uncertainty: scenario tree**



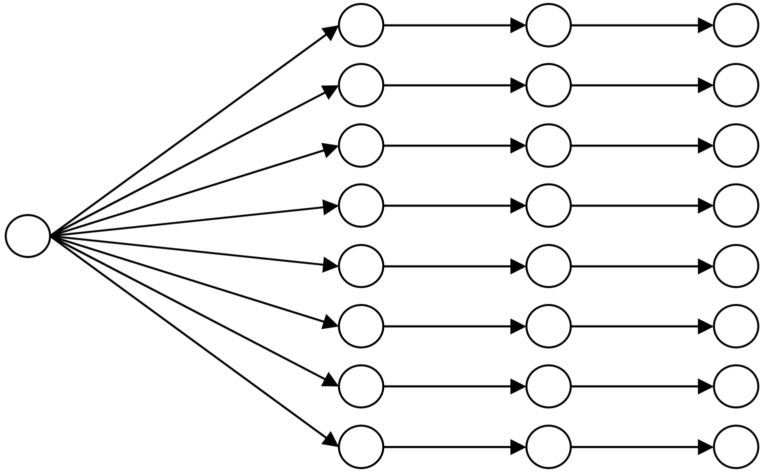
STOCHASTIC APPROACH
Uncertainty modeling

❑ Two-stage model



PRICE SCENARIO GENERATION

- **Scenarios for yearly prices of electricity, natural gas and fuel oil for industrial consumers**
  - ✓ Electricity prices for load levels
  - ✓ Monthly fuel prices
- **No significant correlation between the electricity and fuel prices in the Spanish energy market: independent forecasting algorithms**
- **Price series independent and equiprobable**



STOCHASTIC APPROACH
Risk neutral model

- **Total supply cost c_T^g for each scenario g :**
  - ✓ Contract cost for each scenario
  - ✓ Maintenance cost for each scenario
- **Constraints X : boiler and cogeneration operation, energy balance and contracts**
- **Risk neutral model**

$$\min E[c_T] = \sum_{g \in G} p^g c_T^g$$

$$c_T \in X$$

Expected total cost

Total cost of scenario *g*

Probability function of total cost

Probability of scenario *g*

STOCHASTIC APPROACH
Risk neutral model

❑ **Drawback**

- Does not perform any risk management

❑ **Solution**

- Multiobjective stochastic programming

- Balance among risk and expected cost
- Efficient frontier: set of optimal solutions

❑ **Risk definition for industrial consumers**

- POSSIBILITY OF HIGH COSTS

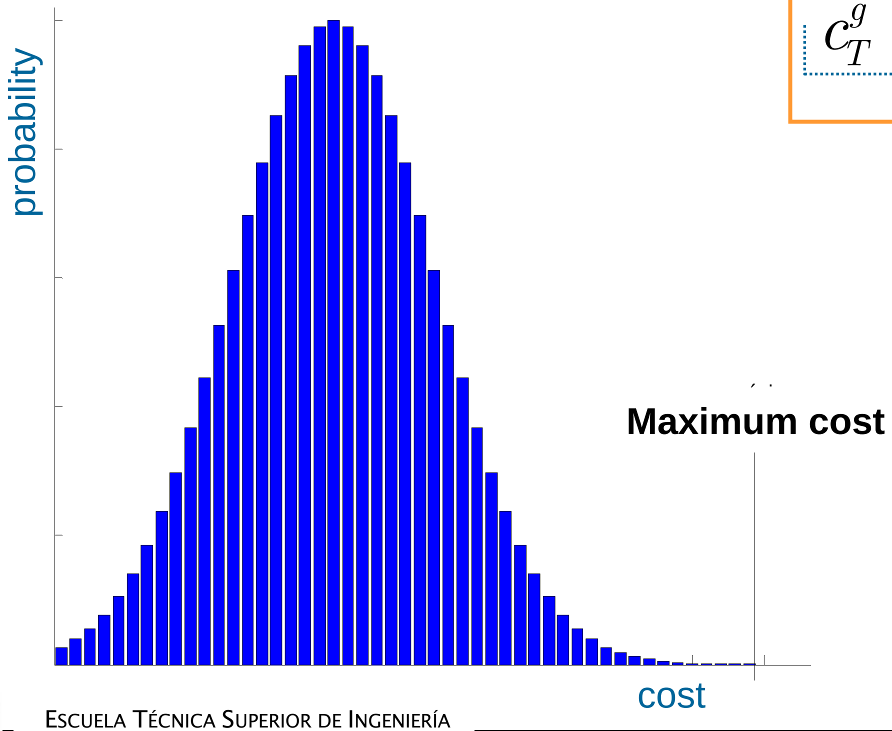
❑ Risk measure

Maximum cost of the distribution

$$\min \quad E[c_T]$$
$$c_T \in X$$
$$c_T^g \le S \qquad \forall g \in G$$

Expected total cost

Cost of any scenario *g* limited to a safety level *S* (risk aversion parameter)



STOCHASTIC APPROACH
Value at Risk (VaR) model

❑ Risk measure

Maximum cost for a certain confidence level α

$$\min \quad VaR_\alpha$$

$$c_T \in X$$

$$E[c_T] \le S$$

$$\sum_{g\in G} p^g \delta^g \le 1-\alpha \quad \forall g\in G$$

$$c_T^g \le VaR_\alpha + M\delta^g \quad \forall g\in G$$

Risk measure

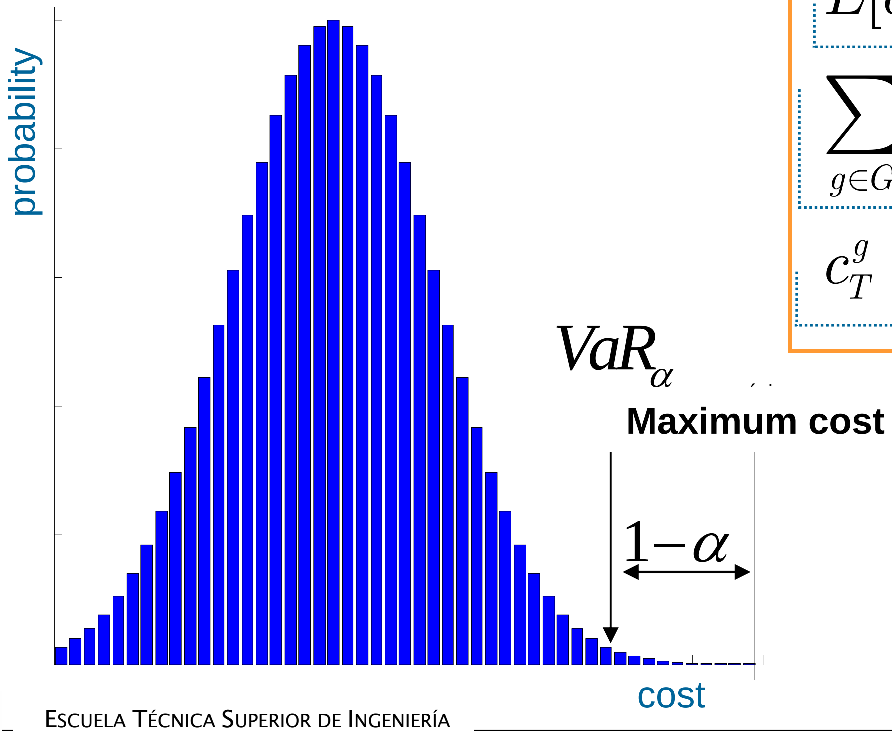
Expected cost limited by the risk aversion parameter *S*

Bounds the # of vars delta to the # of scenarios with value above VaR

Sets the VaR scenario

Auxiliary binary variable for each scenario *g*

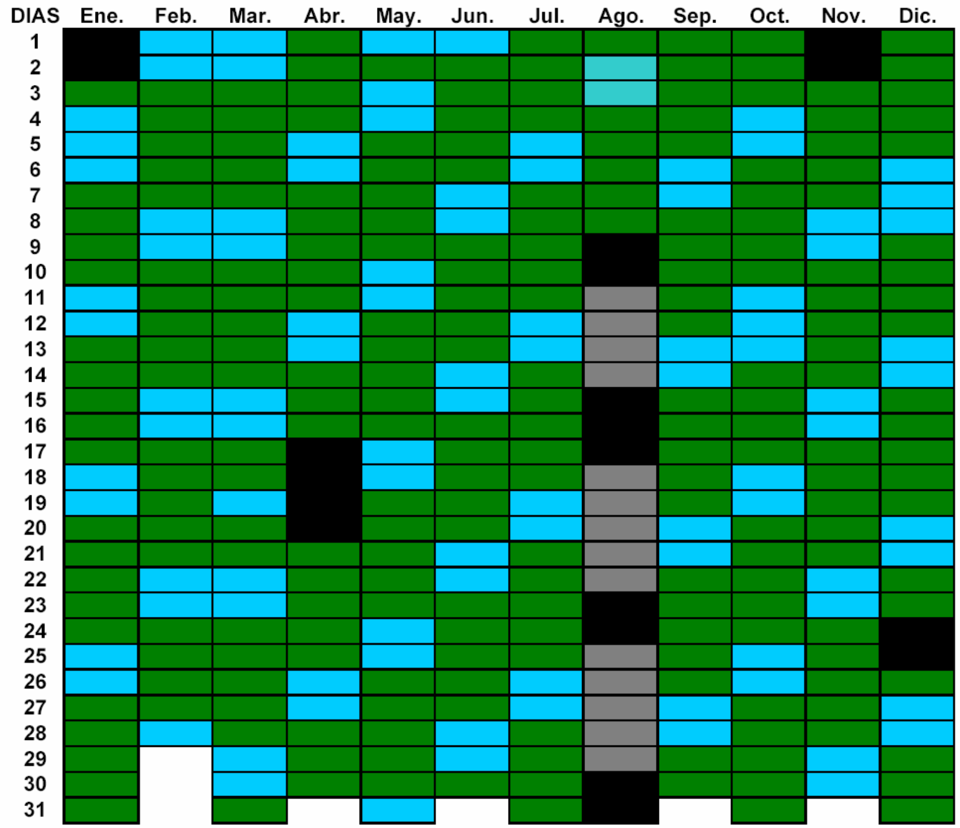
Upper bound for any scenario



CONTENT

NUMERICAL APPLICATION
Input data

- ❑ **Cellulose paper factory**
- ❑ **Day type:** Weekday/Producing   Weekday/Stopped
  Weekend/Producing   **Weekend/Stopped**
- ❑ **3 periods/day type:**
  90 periods



- ❑ **15 price scenarios:**
  - ✓ 5 fuel scenarios
  - ✓ 3 electricity scenarios
- ❑ **1350 nodes**
- ❑ **23 contracts:**
  - ✓ 12 purchase of electricity
  - ✓ 4 purchase of natural gas
  - ✓ 4 purchase of fuel oil
  - ✓ 3 sale of electricity

NUMERICAL APPLICATION
Size and solution

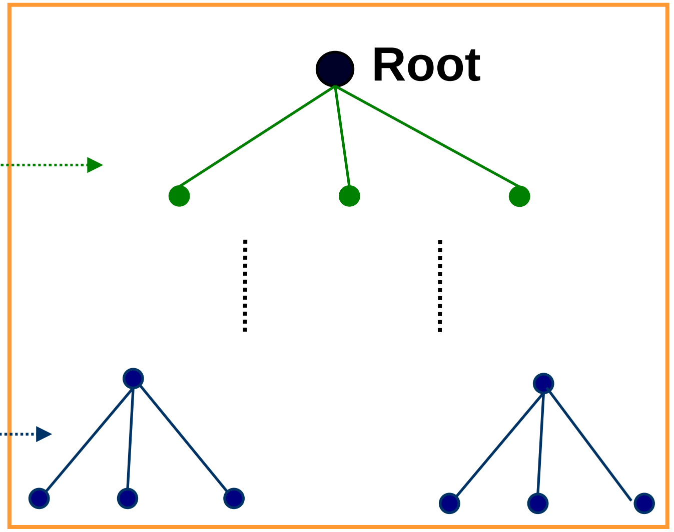
- Coded in GAMS, solved by CPLEX 9.0
- Size

	Deterministic	Stochastic
Constraints	5.883	88.035
Variables	8.677	129.879
Binary	1.087	16.043
Non zero coef.	32.887	492.818

- Branch&Bound algorithm: branching priorities

Contracts
(first level branching)

Boiler and cogeneration state
(last level branching)

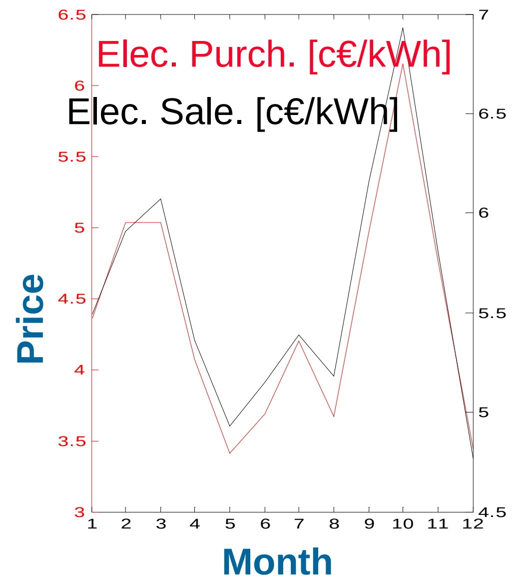


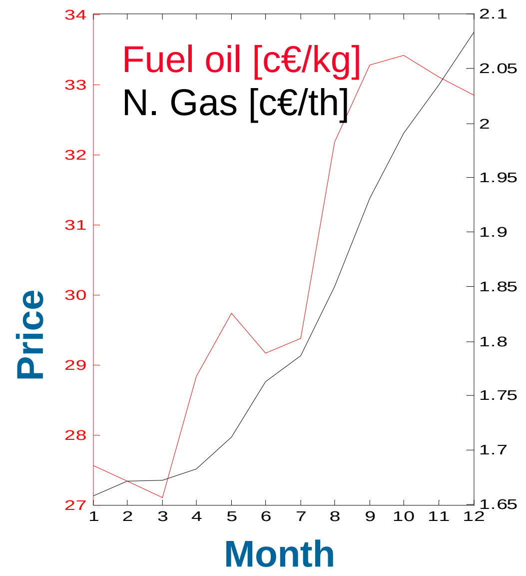
NUMERICAL APPLICATION
Deterministic: Operation 1 scenario

- **Cogeneration operation: 7032 h/year**
  - ✓ Performance: 55.1%, exports 65% of the output
- **Boiler operation: 936 h/year**

Sold or consumed quantities

Mes	Fueloil [t]	Gas natural [km^3]	E^a eléctrica adquirida [MWh]	E^a eléctrica vendida [MWh]
1		468.9	0.5	1196.9
2		458.3		1180.5
3		513.0		1331.5
4		418.9	1.0	1066.5
5	15.0	440.0	86.0	1120.5
6	44.4	320.2	258.1	843.1
7	46.0	332.8	266.7	879.7
8	11.9	86.1	74.4	228.0
9		481.3		1146.5
10		500.8		1277.6
11		450.6	0.5	1146.5
12	57.5	257.5	313.3	670.9
Total	174.8	4728.3	1000.5	12088.4





NUMERICAL APPLICATION
Deterministic: Contracts for the 15 scenarios

❑ Portfolios of different contracts

CONTRACT COST [k€]

High fuel prices: scenarios 1–3. Low fuel prices: scenarios 13–15.

Electricity price: low → 7, medium → 8, high → 9

Scenario	Elect. (purchase): Fixed price	Elect. (purchase): Indexed fixed price	Elect. (purchase): Contract for differences	Fuel oil	Natural gas: Market price	Natural gas: Market price + collar	Elect. (sale): Market price	Elect. (sale): Fixed price	Objective function
1			0.3			1024.5		827.3	658.0
2	30.4			50.9		903.3	754.0		650.6
3		0.3				1022.8	917.8		565.0
4			0.3		992.1			827.3	625.7
5			0.3		979.6		816.5		618.9
6		0.3			990.7		917.9		532.8
7			0.3		911.6			827.3	545.1
8			0.3		911.5		832.4		539.4
9		0.3			912.0		917.7		454.3
10			0.3		893.8			827.2	527.3
11			0.3		894.1		832.7		521.7
12	0.3				895.4		918.8		437.0
13			0.3		831.8			824.1	467.7
14			0.3		834.1		831.1		462.9
15	0.3				836.9		918.2		379.1

Fixed price
Indexed fixed price
Contract for differences
Fixed price
Market price
Market price + collar

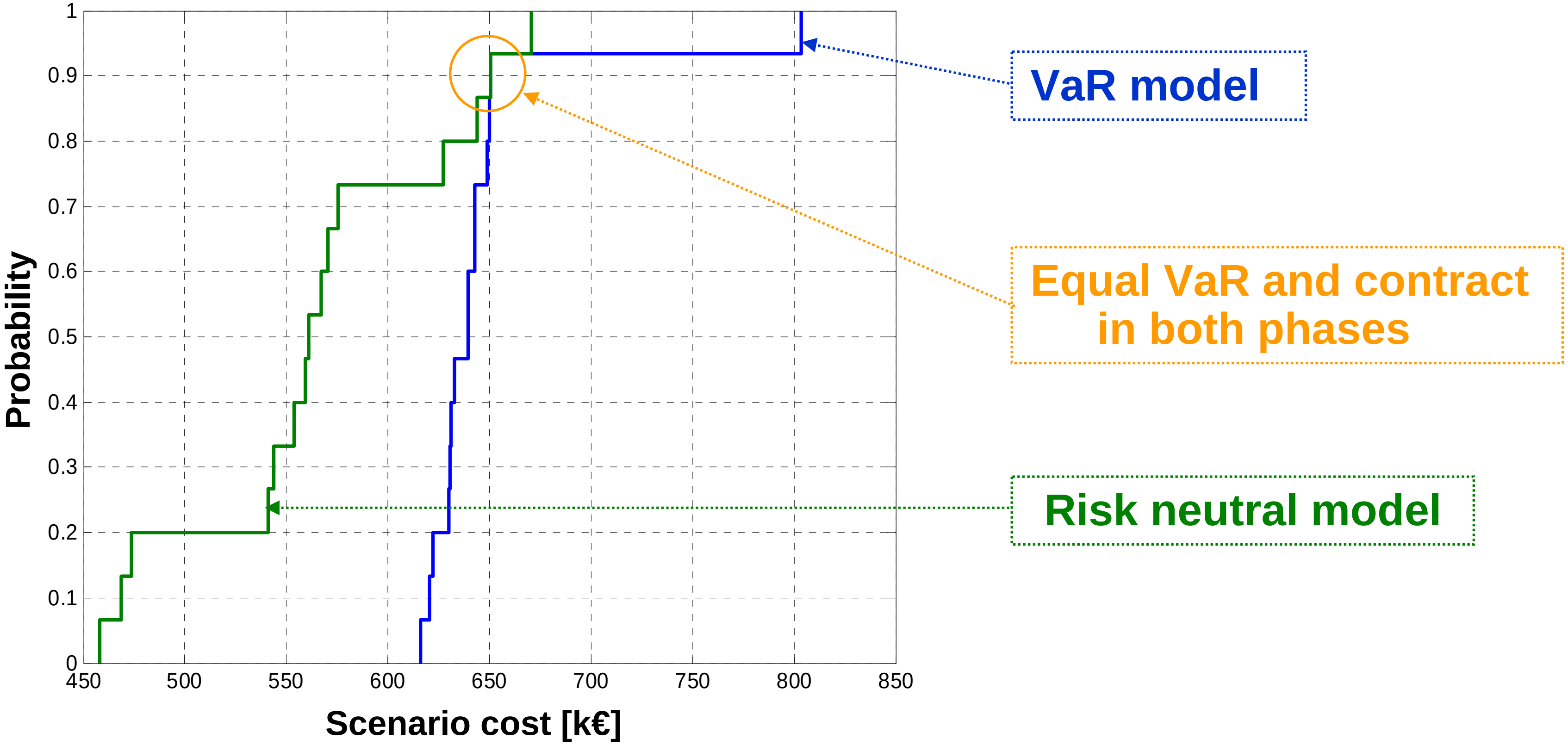
NUMERICAL APPLICATION

Stochastic: efficient frontier

- **Safety-first model**
  - ✓ **Obtaining the efficient frontier:**
    - **First iteration:** solve the risk neutral model to obtain max cost
    - **Remaining iterations** (while the problem is feasible): decrease the risk aversion parameter
  - ✓ **In each iteration we obtain:**
    - Optimal solutions for variables of both stages
    - Different contract portfolios
- **VaR model**
  - ✓ Optimal solution for the first stage
  - ✓ Optimal solution for the second stage only for the VaR scenario
  - ✓ **Drawbacks:**
    - Not always a different contract solution can be obtained when diminishing the risk aversion parameter
    - Optimal plant operation difficult to obtain (not included in the o.f.)

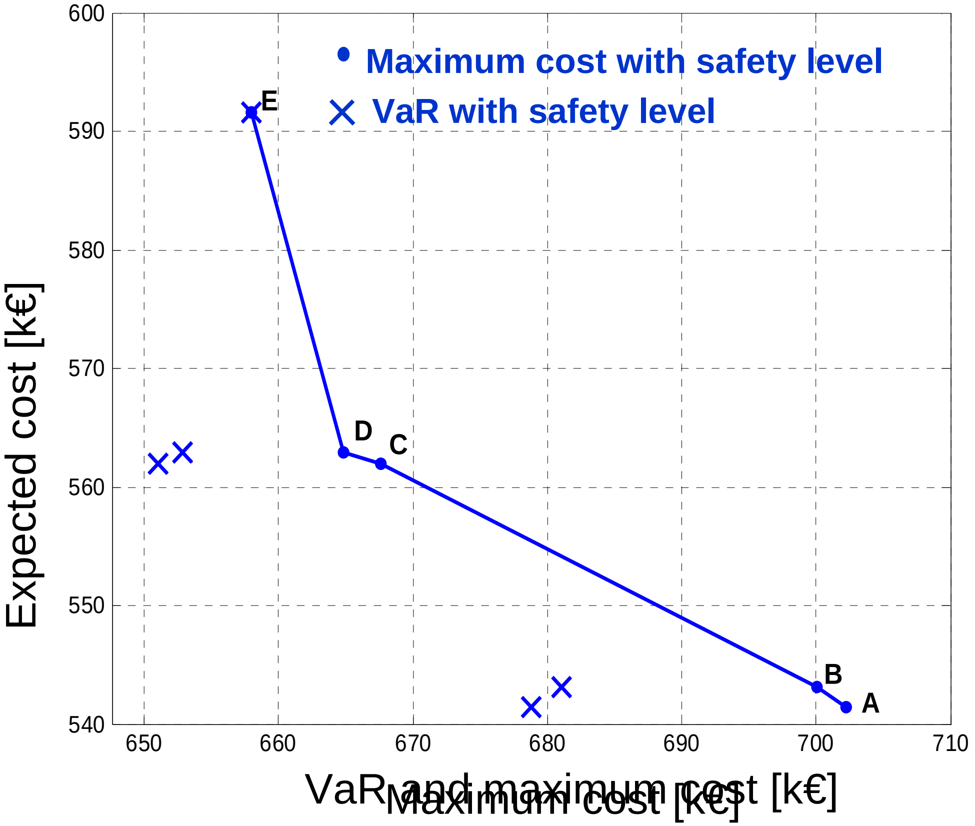
NUMERICAL APPLICATION
Stochastic: Methodology to determine eff. frontier with VaR model

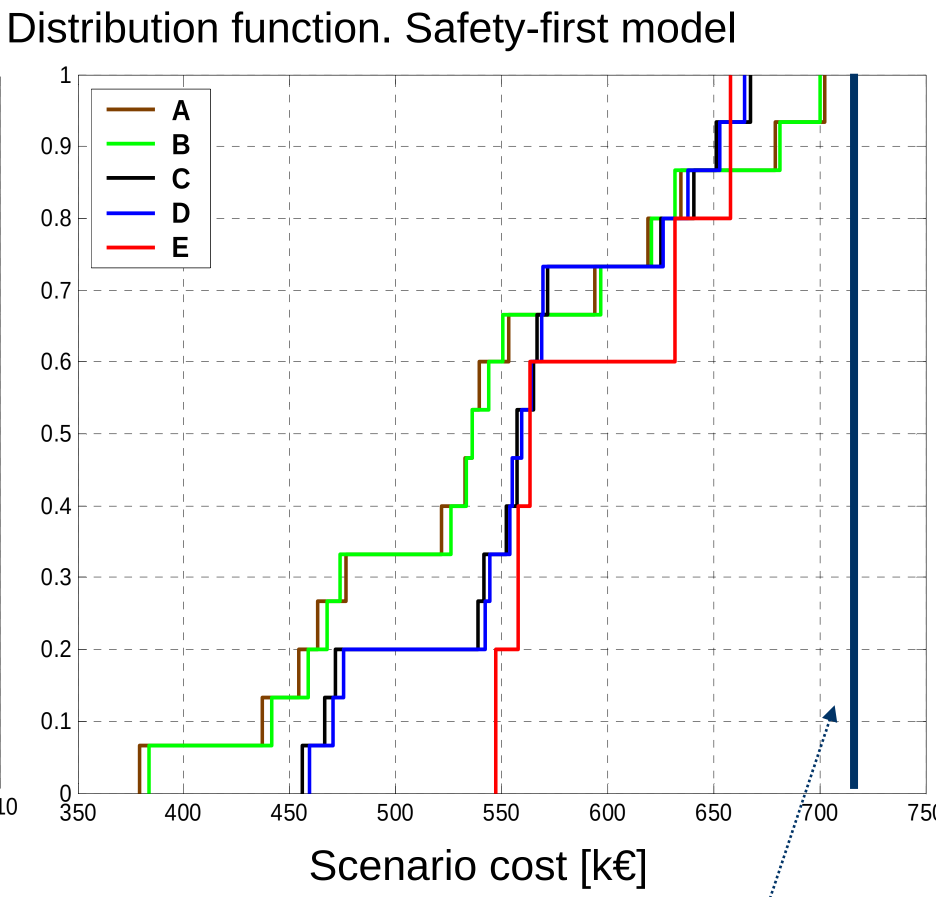
- ❑ **Phase 1: Solving VaR models**
  - ✓ Determine contracts (**first stage variables**)
- ❑ **Phase 2: Solving risk neutral models**
  - ✓ Determine operation (**second stage variables**)



NUMERICAL APPLICATION
Stochastic: efficient frontier

- Safety-first and VaR models (confidence level 0.9)





Solution 1 = A
Solution 3 = C

Fixed price contract

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CONCLUSIONS

❑ Aplications:

- ✓ **The tool developed allows the consumers to:**
  - Decrement the energy bill
  - Control the assumed risk
- ✓ **Other applications:**
  - Retailers: analysis of new contracting possibilities
  - Factory design

❑ Optimization models:

	Solution time (*)	**Risk management**
Deterministic	Reduced (20 s)	Limited
Safety-first level	Reasonable (6 h)	Powerful, low flexibility
VaR	High (22 h)	Powerful, high flexibility

(*) Pentium IV 3 GHz

CONTENT

FUTURE DEVELOPMENTS

- **Extension of proposed models**
  - ✓ **Join optimization of several factories with interannual contracts: multistage stochastic programming**
  - ✓ Different plant configuration
  - ✓ New type of contracts

- **Solution methods for MIP**
  - ✓ Analysis of matrix structure
  - ✓ Decomposition techniques

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